# Sort-free Gaussian Splatting via Weighted Sum Rendering

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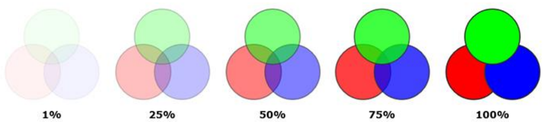
## Motivation



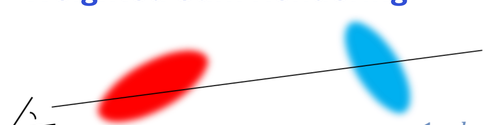

$$\mathbf{C} = \alpha_0\mathbf{c}_0 + (1-\alpha_0)\mathbf{c}_1 + (1-\alpha_0)(1-\alpha_1)\mathbf{c}_2 + \cdots$$

Alpha blending - GPU hardware is very efficient for opaque objects, but not for the transparency, which requires sorting.


Popping artifacts – sorting Gaussians can introduce popping artifacts during view transformation.

***Can we eliminate the sorting step in 3DGS ?***

## Weighted Sum Rendering



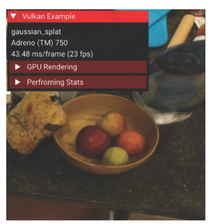


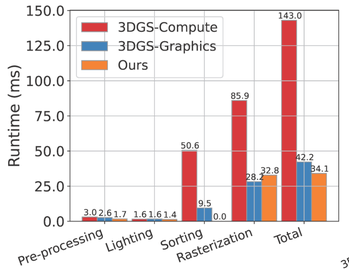
| | | | |
|---|---|---|---|
| Weights | $w(d_i) = 1$ | $\exp(-\sigma d_i^{\beta})$ | $\max\left(0, 1 - \frac{d_i}{\sigma}\right) v_i$ |

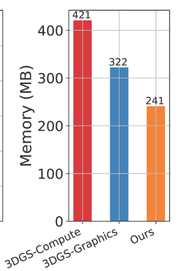
Weighted Sum Rendering

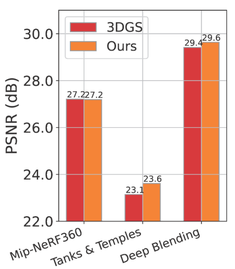
$$\mathbf{C} = \frac{\mathbf{c}_B w_B + \sum_{i=1}^{N} \mathbf{c}_i \alpha_i w(d_i)}{w_B + \sum_{i=1}^{N} \alpha_i w(d_i)}$$

## Performance on Snapdragon 8 gen 3 @ 1920x1080



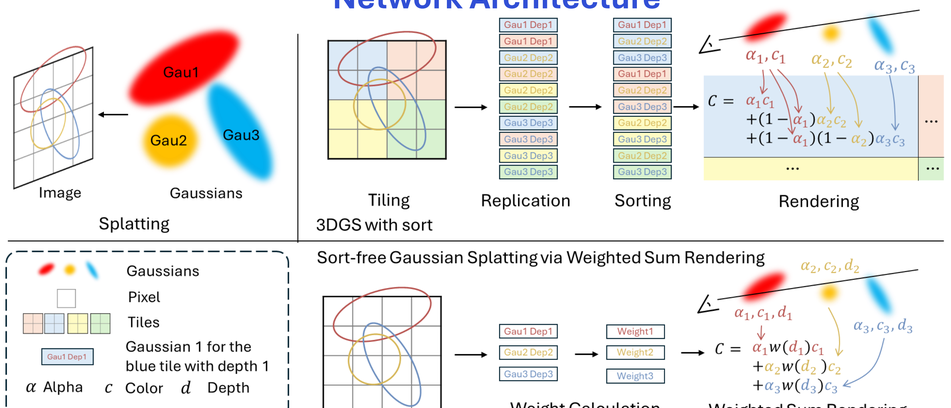



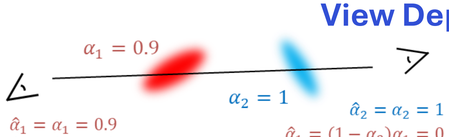

(a) Run on Mobile Phones (b) Runtime Comparison (c) Memory Comparison (d) PSNR comparison

3DGS-Compute: Vulkan compute shaders 3DGS-Graphics: hardware rasterization

## Network Architecture



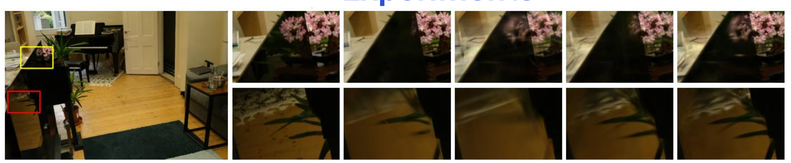

## View Dependent Opacity




$$u_i = Y(\|\mathbf{f} - \mathbf{p}_i\|, \mathbf{H}_i)$$

We substitute our opacity values for an additional set of spherical harmonic coefficients for view dependency.

## Experiments




| Method | Mip-NeRF 360 | | | Tanks & Temples | | | Deep Blending | | |
|---|---|---|---|---|---|---|---|---|---|
| | PSNR↑ | SSIM↑ | LPIPS↓ | PSNR↑ | SSIM↑ | LPIPS↓ | PSNR↑ | SSIM↑ | LPIPS↓ |
| Plenoxels | 23.08 | 0.626 | 0.463 | 21.08 | 0.719 | 0.379 | 23.06 | 0.795 | 0.510 |
| INGP-Base | 25.30 | 0.671 | 0.371 | 21.72 | 0.723 | 0.330 | 23.62 | 0.797 | 0.423 |
| INGP-Big | 25.59 | 0.699 | 0.331 | 21.92 | 0.745 | 0.305 | 24.96 | 0.817 | 0.390 |
| M-NeRF360 | **27.69** | 0.792 | 0.237 | 22.22 | 0.759 | 0.257 | 29.40 | 0.901 | 0.245 |
| 3DGS | 27.21 | **0.815** | 0.214 | 23.14 | 0.841 | 0.183 | 29.41 | **0.903** | 0.243 |
| LC-WSR | 27.19 | 0.804 | **0.211** | **23.61** | **0.842** | **0.177** | **29.63** | 0.902 | **0.229** |

Our method achieved comparable results with 3DGS.

| Method | Task | Mip-NeRF360 | | | | | | | | | Tanks&Temples | | Deep Blending | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | bicycle | flowers | garden | stump | treehill | room | counter | kitchen | bonsai | truck | train | drjohnson | playroom |
| 3DGS-Compute | Pre-processing | 12.84 | 7.05 | 10.15 | 6.94 | 7.53 | 3.99 | 3.02 | 4.46 | 3.12 | 6.29 | 3.03 | 7.50 | 6.04 |
| | Lighting | 4.57 | 3.26 | 5.19 | 3.43 | 3.37 | 1.84 | 1.55 | 3.07 | 1.40 | 3.53 | 2.41 | 2.61 | 2.40 |
| | Sorting | 246.65 | 122.68 | 210.35 | 180.23 | 139.98 | 70.83 | 50.57 | 89.96 | 50.63 | 105.83 | 60.83 | 140.64 | 110.97 |
| | Rasterization | 1239.12* | 115.18 | 608.19* | 265.27 | 147.08 | 140.16 | 85.94 | 177.01 | 73.43 | 165.64 | 130.23 | 212.10 | 167.09 |
| | Total | 1511.96 | 253.60 | 842.15 | 463.06 | 303.68 | 219.31 | 143.03 | 277.35 | 130.58 | 285.11 | 198.01 | 367.93 | 290.32 |
| 3DGS-Graphics | Pre-processing | 13.27 | 7.82 | 13.73 | 10.46 | 8.01 | 3.40 | 2.62 | 4.09 | 2.62 | 5.84 | 2.35 | 7.22 | 5.57 |
| | Lighting | 5.32 | 3.66 | 5.67 | 3.68 | 3.80 | 2.00 | 1.61 | 3.55 | 1.51 | 4.03 | 2.68 | 2.94 | 2.71 |
| | Sorting | 40.26 | 24.79 | 38.25 | 31.09 | 25.47 | 11.23 | 9.47 | 13.76 | 9.17 | 19.16 | 7.43 | 23.13 | 18.43 |
| | Rasterization | 618.83* | 246.47* | 697.81* | 344.72* | 208.28* | 32.50 | 28.22 | 52.84 | 30.86 | 78.24 | 39.70 | 164.25* | 82.45 |
| | Total | 678.08 | 283.11 | 755.89 | 390.33 | 245.95 | 49.46 | 42.25 | 74.56 | 44.47 | 107.64 | 52.48 | 197.86 | 109.46 |
| LC-WSR | Pre-processing | 6.83 | 3.92 | 5.53 | 6.46 | 4.63 | 1.94 | 1.67 | 2.74 | 1.64 | 3.42 | 1.61 | 4.61 | 2.48 |
| | Lighting | 4.07 | 2.81 | 4.36 | 3.67 | 3.23 | 1.41 | 1.35 | 2.98 | 1.16 | 3.21 | 2.31 | 2.91 | 1.70 |
| | Rasterization | 67.84 | 28.30 | 57.84 | 57.25 | 52.99 | 45.44 | 32.82 | 68.51 | 37.52 | 52.89 | 48.98 | 78.11 | 49.87 |
| | Total | 78.99 | 35.28 | 67.90 | 67.63 | 61.11 | 49.02 | 34.06 | 74.47 | 40.63 | 59.75 | 53.13 | 85.85 | 54.28 |

Our method is on average 1.23× faster than 3DGS-Graphics.

| Method | Mip-NeRF 360 | | | Tanks & Temples | | | Deep Blending | | |
|---|---|---|---|---|---|---|---|---|---|
| | PSNR↑ | SSIM↑ | LPIPS↓ | PSNR↑ | SSIM↑ | LPIPS↓ | PSNR↑ | SSIM↑ | LPIPS↓ |
| Ours | 27.19 | 0.804 | 0.211 | 23.61 | 0.842 | 0.177 | 29.63 | 0.902 | 0.229 |
| w.o. learnable parameters | 23.19 | 0.711 | 0.318 | 21.55 | 0.788 | 0.245 | 27.92 | 0.893 | 0.260 |
| w.o. view-dependent opacity | 25.88 | 0.784 | 0.251 | 21.83 | 0.798 | 0.237 | 29.27 | 0.902 | 0.249 |

Ablation study on learnable parameters and view-dependent opacity.